Mg II Selected Absorbers: Ionization Structures and a Survey of Weak Systems

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Abstract. First results from a study of high ionization absorption properties in ~ 30 Mg II absorption selected galaxies are presented. We have tested for correlations of Mg II, C IV, Si IV, N V, and O VI equivalent widths with the galaxy properties and Mg II gas kinematics. The results are suggestive of multi–phase halos with little to no global ionization gradient with impact parameter. C IV may arise in both the Mg II–Ly α clouds and a high ionization "halo" traced by O VI. We also report on an unbiased survey for weak Mg II systems using HIRES/Keck spectra. At $\langle z \rangle = 0.9$, we find $dN/dz = 1.6 \pm 0.1$ for $0.02 < W(\lambda 2796) < 0.3$ Å and that weak systems comprise $\sim 65\%$ of all Mg II absorbers. In all but one case, the weak Mg II systems exhibit Fe II absorption with $\langle \log N({\rm Fe~II})/N({\rm Mg~II}) \rangle = -0.3 \pm 0.4$ measured for the sample. We suggest that weak Mg II absorbers comprise a substantial yet–to–be explored population. If weak systems select the LSB and/or dwarf galaxy population, then the weakest Mg II absorbers may provide one of the most sensitive tracers of chemical enrichment and evolution of the UV background from z=2 to z=0.

1 Mg II Selected Galaxies and Absorbers

Our understanding of Mg II absorbers and their relationship to normal field galaxies has grown considerably in recent years [1, 10, 2]. Yet there remain controversial and unanswered questions regarding detailed *cause and effect* relationships between gas seen in absorption and galaxies seen in emission. How do absorbing gas chemical, ionization, and kinematic conditions depend upon and influence star formation histories, merging events, and luminous morphologies of associated galaxies? It is hoped clues to this question can be extracted from observed trends, or non-trends, of the low and high ionization gas properties with the galaxy properties and/or gas kinematics.

The largest uniform survey of Mg II systems is complete to $W(\lambda 2796) = 0.3 \text{ Å}$ [8]. The number density of the very weakest Mg II absorbers and their chemical and ionization conditions remain unexplored. What is their number density, what class of *luminous* object does $W(\lambda 2796) \sim 0.1 \text{ Å}$ Mg II absorption select, and what astrophysics can we extract from these systems?

In this contribution we report first results from (1) an HST Archival study of the neutral hydrogen and high ionization absorption lines of galaxies for which the luminous properties and Mg II gas kinematics are measured, and (2) an unbiased survey of $W(\lambda 2796) < 0.3$ Å systems.

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2 Ionization Structure of $W(\lambda 2796) > 0.3$ Å Systems

We have compiled a database of ~ 30 Mg II absorption selected galaxies by combining the galaxies of Steidel, Dickinson, & Persson [9], the HIRES Mg II absorption profiles of Churchill, Vogt, & Charlton [3] and Archival FOS/HST spectra of neutral hydrogen and high ionization absorption lines. The FOS spectra reduction and line identification methods were identical to those of the QSO Absorption Line Key Project [5, 7].

We tested for correlations of ionization conditions and strengths of the absorbing gas with: (1) Mg II velocity spread, ω_v , (2) galaxy B and K magnitudes and B-K colors, and (3) projected galactocentric distance, D. In Table 1, a selection of Kendall τ rank correlation tests are tabulated. Columns 3, 4, and 5 are the number of data points, the Kendall τ and the significance level that the tested quantities are not uncorrelated in units of σ .

Table 1. Rank Correlation Tests

Property 1	Property 2	N	$ au_{ m k}$	$N(\sigma)$	Notes
W(C IV)/W(Mg II)	W(Mg II)	19	-0.65	3.86	
W(Mg II)	$W(\text{Ly }\alpha)$	19	0.48	2.85	
W(S iv)/W(C iv)	W(C IV)	12	-0.58	2.65	
W(C iv)/W(Mg ii)	$W(\text{Ly }\alpha)$	14	-0.53	2.64	
W(O VI)	W(C IV)	6	0.87	2.44	
W(C IV)	W(MgII)	19	0.21	1.23	
W(C IV)	$W(\text{Ly }\alpha)$	19	0.06	0.28	
W(C IV)	$\omega_v({ m Mg~II})$	17	0.61	3.43	
W(Mg II)	$\omega_v({ m Mg~II})$	30	0.27	2.12	
W(O VI)	$\omega_v({ m Mg~II})$	8	0.29	0.99	
W(Mg II)	D	19	-0.30	1.78	1 pt dominates
W(C IV)/W(Mg II)	D	11	0.40	1.73	1 pt dominates
$W(\text{Ly }\alpha)$	D	8	-0.36	1.24	1 pt dominates
W(C IV)	D	11	0.11	0.47	

The correlation tests are suggestive of multi-phase ionization with C IV present in both phases. The clouds of Mg II trace the neutral hydrogen (Ly α) in the galaxies and have velocity spreads of $\sim 70~\rm km~s^{-1}$. The clouds may be embedded in an extended "halo" traced by O VI absorption [1]. W(C IV) does not trace W(Mg II) but appears to trace W(O VI). We infer that a significant fraction of the C IV is spatially distributed with the putative O VI halo. However, the W(C IV) is strongly correlated with the Mg II velocity spread, whereas W(O VI) is not. This suggests many Mg II clouds have ionization structures in which C IV surrounds their lower ionization Ly α -Mg II cores.

There is no evidence for correlations above the 1.5σ level of absorption strengths, W(X), and ionization levels, $W(X_1)/W(X_2)$, with the galaxy magnitudes and colors. Apparently, for $W(\lambda 2796) > 0.3$ Å selected systems, the stellar population is not strongly interfaced with the absorption properties.

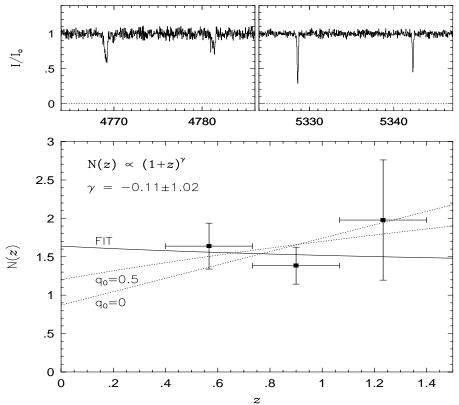


Figure 1: (upper) Example of weak Mg II absorbers. — (lower) The number density of W(2796) < 0.3 Å absorbers from a redshift pathlength of ~ 15 . The dotted lines show the slopes of the best fit no–evolution models.

There is no compelling evidence for strong correlations of absorption properties with projected galactocentric distance, D. Perhaps the spatial distribution of Mg II clouds is independent of galactocentric distance and there is no *smooth* ionization gradient surrounding these galaxies. A study that includes the galaxy morphologies, line of sight orientations, and stellar velocities may reveal a yet–unknown interrelationship between absorbing gas and galaxies.

3 The Properties of $W(\lambda 2796) < 0.3$ Å Systems

Because the lines of sight studied with the HIRES spectra were selected based upon the presence of known $W(\lambda 2796)>0.3$ Å absorbers [8], the number density of these systems is biased too high in our sample. However, the total redshift path is unbiased for $W(\lambda 2796)<0.3$ Å systems. A systematic search for weak Mg II doublets has been performed for a redshift path of ~ 15 over 0.4 < z < 1.4 complete to $W(\lambda 2796)=0.02$ Å (5σ) [4]. Following Lanzetta et al. [6], the number density per unit redshift was computed.

In Figure 1, the number density of $W(\lambda 2796) < 0.3$ Å systems is shown. We find $dN/dz = 1.6 \pm 0.1$ at $\langle z \rangle = 0.9$. Accounting for $dN/dz = 0.9 \pm 0.1$ found for $W(\lambda 2796) > 0.3$ Å systems by Steidel & Sargent [8], the number density of Mg II systems complete to $W(\lambda 2796) = 0.02$ Å is 2.5 ± 0.2 at $\langle z \rangle = 0.9$. The $W(\lambda 2796) < 0.3$ Å systems comprise $\sim 65\%$ of all Mg II absorbing systems at low redshift. For the sample, $\langle \log N(\text{Fe II})/N(\text{Mg II}) \rangle = -0.3 \pm 0.4$.

Applying the maximum likelihood technique to the parameterized relation $dN/dz \equiv N(z) = N_0(1+z)^{\gamma}$, we obtained $\gamma = -0.1 \pm 1.0$. This poorly constrained value is not inconsistent with a non–evolving population. A larger sample with extended redshift coverage to z>2 would allow the redshift evolution of these weakest systems to be tested. We suggest two types of evolution are expected over 0.4 < z < 2.2. First, dN/dz likely increases with decreasing redshift as the ionizing UV background becomes less intense. Second, the ratio of N(Fe II)/N(Mg II) should increase with decreasing redshift for two reasons, provided the cloud densities do not strongly evolve. (1) For UV background photoionization, the higher J_0 at higher z produces a smaller ratio. This is consistent with the observed W(C IV)/W(Mg II) evolution [1]. (2) The chemical build up of iron–group elements (a SN Ia process taking several Gyr) would gradually increase the Fe/Mg abundance ratios following the $z \sim 2$ peak star formation epoch of the universe in which Type II SNe disperse α –group elements such as silicon and magnesium.

If weak systems are closely associated with LSB and/or dwarf galaxies, there in fact may be a narrow redshift range at $z\sim 1$ over which a "break" from UV background to local late–type stellar dominated photoionization occurs as the UV background falls below a critical level. Since iron–group enrichment is gradual, such a break could be inferred from a rapid jump in the fraction of weak Mg II systems having strong Fe II absorption. The population of weak Mg II systems may provide one of the most sensitive probes of the UV background evolution from z=2 to z=0.

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References

- [1] Bergeron, J., Petitjean, P., Sargent, W.L.W., et al. 1994, ApJ, 436, 33
- [2] Churchill, C.W., Steidel, C.C., & Vogt, S.S., 1996, ApJ, 471, 164
- [3] Churchill, C.W., Vogt, S.S., & Charlton, J.C. 1998, ApJS, in prep
- [4] Churchill, C.W., et al. 1998, ApJ, in prep
- [5] Jannuzi, B.T., et al. 1998, ApJS, in prep
- [6] Lanzetta, K.M., Turnshek, D.A., & Wolfe, A. 1987, ApJ, 322, 739
- [7] Schneider, D.P., et al. 1993, ApJS, 87, 45
- [8] Steidel, C.C., & Sargent, W.L.W., ApJS, 80, 1
- [9] Steidel, C.C., Dickinson, M., Perrson, S.E. 1994, ApJ, 437, L75
- [10] Steidel, C.C. 1995, in QSO Absorption Lines, ed. G. Meylan (Berlin:Springer)